OPEN ACCESS

KING'S College LONDON

King's Research Portal

Document Version
Publisher's PDF, also known as Version of record

Link to publication record in King's Research Portal

Citation for published version (APA):
Charlton, P. H., Bonnici, T. A., Tarassenko, L., Clifton, D., Beale, R., & Watkinson, P. (2016). An Assessment of Algorithms to Estimate Respiratory Rate from the Electrocardiogram and Photoplethysmogram. In *MEIBioeng16*

Citing this paper
Please note that where the full-text provided on King's Research Portal is the Author Accepted Manuscript or Post-Print version this may differ from the final Published version. If citing, it is advised that you check and use the publisher's definitive version for pagination, volume/issue, and date of publication details. And where the final published version is provided on the Research Portal, if citing you are again advised to check the publisher's website for any subsequent corrections.

General rights
Copyright and moral rights for the publications made accessible in the Research Portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognize and abide by the legal requirements associated with these rights.

•Users may download and print one copy of any publication from the Research Portal for the purpose of private study or research.
•You may not further distribute the material or use it for any profit-making activity or commercial gain
•You may freely distribute the URL identifying the publication in the Research Portal

Take down policy
If you believe that this document breaches copyright please contact librarypure@kcl.ac.uk providing details, and we will remove access to the work immediately and investigate your claim.

Download date: 04. May. 2023

An assessment of algorithms to estimate respiratory rate from the ECG and PPG signals

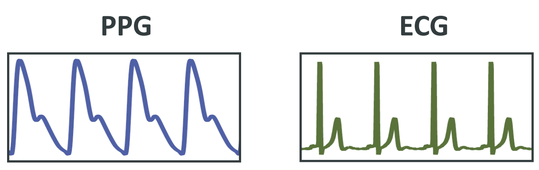
Peter H. Charlton [123], Timothy Bonnici [123], Lionel Tarassenko [2], David A. Clifton [2], Richard Beale [13], Peter J. Watkinson [4]

[1] King's College London; [2] University of Oxford; [3] Guy's and St Thomas' NHS Foundation Trust; [4] Oxford University Hospitals

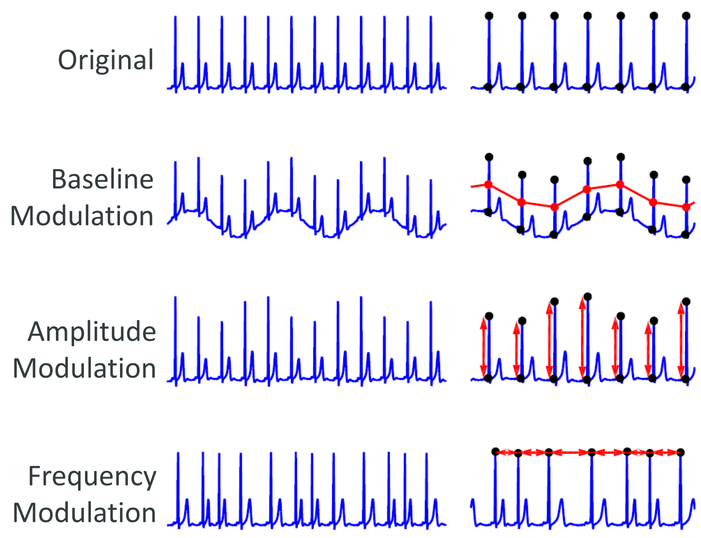
1. Estimating respiratory rate (RR) from the ECG and PPG

The importance of RR

Respiratory rate (RR, number of breaths per minute) is an informative indicator of physiological state. RR is used for diagnosing diseases such as pneumonia. It also changes in the hours before rapid deteriorations such as cardiac arrests, giving early warning. However, it is usually measured by hand. ECG and PPG signals may provide an alternative approach ...



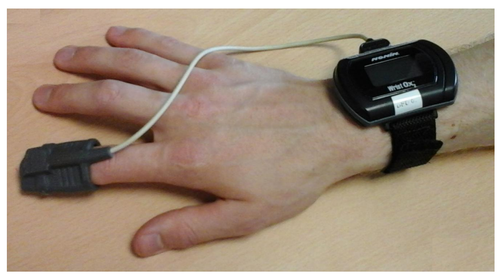
The influence of respiration on the ECG and PPG



Respiration influences the ECG and PPG in three ways. This figure demonstrates extraction of the respiratory modulations of the ECG. Individual heart beats are detected (black dots). The three variations can then be extracted on a beat-by-beat basis.

ECG and PPG signals

The electrocardiogram (ECG) and pulse oximetry (PPG) signals are widely measured in clinical practice to assess the state heart activity and blood oxygenation. They can also be measured continuously using wearable sensors:



2. Assessment of respiratory rate algorithms

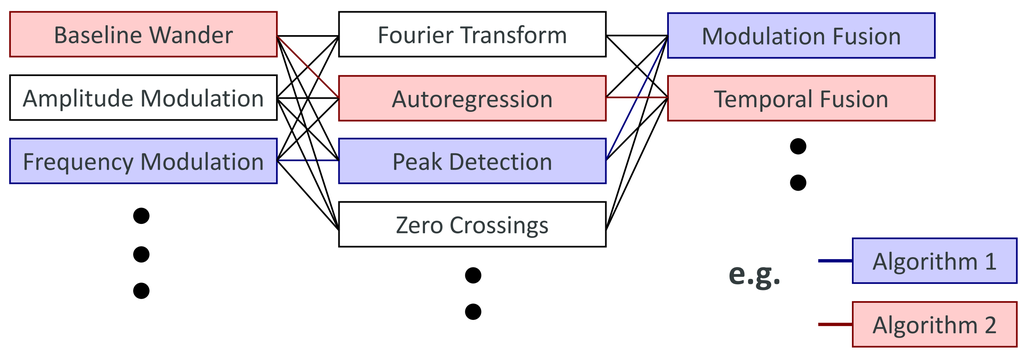
RR algorithms

Algorithms to estimate RR from the ECG or PPG consist of three stages (see right). Several techniques have been proposed for each stage. Consequently, over 100 algorithms – combinations of techniques – have been proposed. However, their performances have not been compared.

In this study we performed a comprehensive assessment of 314 algorithms. They were constructed by combining techniques from each of the three stages. Two examples are highlighted (see right).

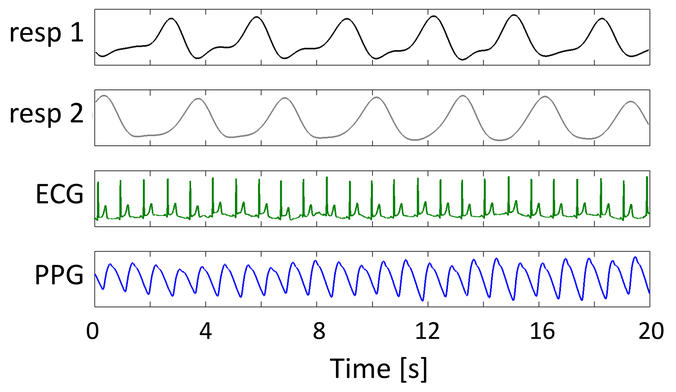
The three fundamental stages of an RR algorithm

An algorithm can be constructed using any of the interchangeable techniques for each stage



Dataset

We collected a benchmark dataset of ECG, PPG and reference respiratory signals from 39 young, healthy volunteers (see sample below). RRs were estimated from the ECG, PPG, and reference signals using 32 s windows of data.



3. Results

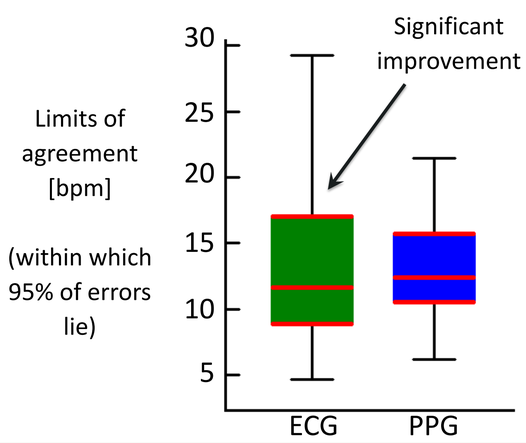
Algorithm performance

The best performance achieved when using the **ECG** was an error of 0.0 ± 4.7 breaths per min (bpm). This indicates a mean error of 0 bpm, and that 95% of the errors were less than 4.7 bpm. The best performance for the **PPG** was an error of 1.0 ± 6.2 bpm.

Both these results were achieved using algorithms which were novel combinations of techniques. Both algorithms fused RRs estimated simultaneously using each of the three types of respiratory modulation.

Comparison between ECG and PPG

The performance of algorithms improved slightly when using the ECG as an input rather than the PPG. However, performance was still reasonable with the PPG:



4. Relevance

Comparison to clinical practice

One of the reference respiratory signals acquired was an impedance pneumography signal, which is commonly used to monitor RR in critical care. It provided a performance of -0.2 ± 5.4 bpm, slightly worse than the best algorithm.

Therefore, the best algorithms may perform sufficiently well for clinical use. However, this assessment was conducted in ideal conditions, with young healthy subjects. Therefore, we are now assessing the performance of algorithms in the clinical setting to see if these conclusions hold.

Equipping future researchers

Both the algorithms and the benchmark dataset used in this study are publicly available at:

http://peterhcharlton.github.io/RRest

These resources allow researchers to compare the performance of their own algorithms against those assessed in this study.

Accompanying Paper

Charlton P.H. and Bonnici T. et al. An assessment of algorithms to estimate respiratory rate from the electrocardiogram and photoplethysmogram, Physiological Measurement, 37(4), 2016, DOI: 10.1088/0967-3334/37/4/610

Contact: Peter.Charlton [at] kcl.ac.uk

PHC and TB contributed equally to this work. It was supported by the UK EPSRC (Grant EP/H019944/1), the NIHR Biomedical Research Centre at Guy's and St Thomas' NHS Foundation Trust in partnership with King's College London, the NIHR Oxford Biomedical Research Centre Programme, the Oxford and King's College London Centres of Excellence in Medical Engineering funded by the Wellcome Trust and EPSRC under grant no. WT88877/Z/09/Z and grant no. WT088641/Z/09/Z, a Royal Academy of Engineering (RAEng) Research Fellowship awarded to DAC, and an EPSRC Challenge Award to DAC. The views expressed are those of the authors and not necessarily those of the EPSRC, NHS, NIHR, Department of Health, Wellcome Trust, or RAEng

KING'S HEALTH PARTNERS

Pioneering better health for all